Rosenzweig et al. 2007. Attributing Physical and Biological Impacts to Anthropogenic Climate Change.

Supplementary Information

Joint Attribution

We conducted a joint attribution study across multiple physical and biological systems at both global and continental scales by demonstrating statistical consistency of observed changes (which are very unlikely to be due to natural internal variability of the systems themselves or other driving forces) in natural systems with warming and conducting spatial analyses that show that the co-location of observed significant changes in natural systems and areas of warming is very unlikely to be due to natural variability of the climate (Fig. SI-1). Combined with the attribution of global and continental-scale warming to anthropogenic climate forcing demonstrated by IPCC WGI AR4, this analysis proves joint attribution of observed impacts.

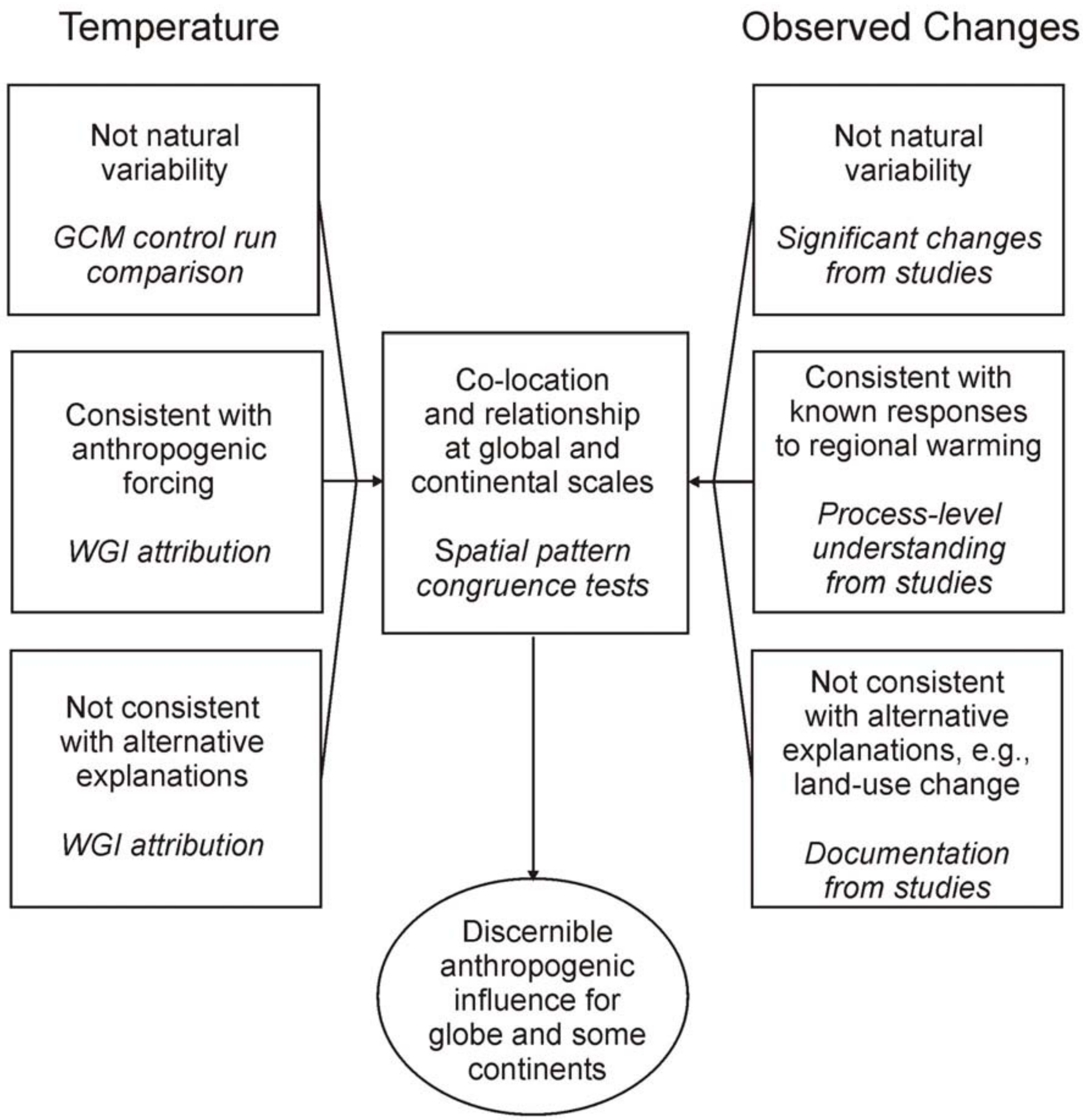

Fig. SI-1. Methods of joint attribution used in this study.

Database and GIS of observed changes and temperatures

We developed a database of observations from peer-reviewed papers (primarily published since the IPCC Third Assessment Report [1]), documenting the data series in terms of system, region, longitude and latitude, dates and duration, statistical significance, type of impact, and whether or not land use was identified as a driving factor (Table SI-1). Table SI-2 summarizes literature related to climate effects of land-use change. Authors specified latitudes and longitudes for data series documented in the studies, obtained from study authors, or estimated from NASA WorldWind. Data for the system changes are taken from ~80 studies (of which ~75 are new since the TAR) containing >29,000 data series. Significant observed changes documented since the TAR were divided into the categories of cryosphere, hydrologic systems, coastal processes, marine and freshwater biological systems, terrestrial biological systems, and agriculture and forestry. Observations that were not significant were not included in order to base the analysis on a statistically defined data set of changes consistent or not consistent with warming. Since cases of 'no change' tend to be underrepresented in the published literature, those found were excluded to eliminate bias.

Studies were selected that (1) demonstrate a statistically significant trend in change in either direction in systems related to temperature or other climate change variable as described by the authors; and (2) contain data for at least 20 years between 1970 and 2004, although study periods may extend earlier or later. Observations in the studies are characterized as 'change consistent with warming,' and 'change not consistent with warming.' The changes documented in the database as 'consistent with warming' are indicative of known relationships between warming and its impacts on physical and biological systems.

Two regional temperature databases were overlaid in Arcview GIS with the database of observed changes. The two temperature datasets were HadCRUT3[2] and GHCN-ERSST[3].

Table SI-1. Studies in database, number of data series, and likelihood of other driving forces directly affecting observed changes in physical and biological systems.

		Direct effects of other driving forces*	
Studies	# of data series	*Likelihood of other driving forces besides temperature affecting observed physical or biological change directly (e.g., habitat disturbance, pollution, invasive species, over-fishing, acid deposition) based on statements by study authors and expert judgment.	
Abu-Asab, M. S., P. M. Peterson, S. G. Shetler and S. S. Orli 2001: Earlier plant flowering in spring as a response to global warming in the Washington, DC, area. *Biodiversity and Conservation* **10**: 597.	76	Very unlikely	Change related to warming not other factors. Advances in flowering of 89 species are directly correlated with local increases in min temperature.
Ahas, R., A. Aasa, A. Menzel, V. G. Fedotova and H. Scheifinger 2002: Changes in European spring phenology. *International Journal of Climatology* **22**(14): 1727-1738.	17	Unlikely	Change related to warming not other factors.
Allan, J. C. and P. D. Komar 2006: Climate Controls on U.S. West Coast Erosion Processes. *Journal of Coastal Research* **3**(22): 511-529.	7	Very unlikely	Authors teased out ENSO signal. Since offshore processes (wave heights, etc) were measured, land use change cannot be seen as a driver.
Amstrup, S. C., I. Stirling, T. S. Smith, C. Perham and G. W. Thiemann 2006: Recent observations of intraspefic predation and cannibalism among polar bears in the southern Beaufort Sea. *Polar Biology*(29): 997-1002.	2	Very unlikely	Authors feel that the events are related to ice-free seasons that have occurred in the region in recent years.

Arendt, A. A., Echelmeyer, K. A., Harrison, W. D., Lingle, C. S., and Valentine ,V. B. 2002: Rapid wastage of Alaska glaciers and their contribution to rising sea level. *Science* **297**: 382–386.	56	Very unlikely	Changes are enhanced because of positive feedbacks. Authors state that the retreat is likely initiated by negative mass balance and these resulting unstably dynamics then lead to rapid thinning.
Atkinson, A., V. Siegel, E. Pakhomov and P. Rothery 2004: Long-term decline in krill stock and increase in salps within the Southern Ocean. *Nature* **432**(7013): 100-103.	35	Very unlikely	The decline in krill was correlated with declining sea ice.
Barbraud, C. and H. Weimerskirch 2001: Emperor penguins and climate change. *Nature* **411**(6834): 183-186.	1	Very unlikely	"We show that over the past 50 years, the population of emperor penguins (Aptenodytes forsteri) in Terra Adelie had declined by 50% because of a decrease in adult survival…at the time there was a prolonged abnormally warm period with reduced sea-ice extent."
Barry, J. P., C. H. Baxter, R. D. Sagarin and S. E. Gilman 1995: Climate-Related, Long-Term Faunal Changes in a California Rocky Intertidal Community. *Science* **267**(5198): 672-675.	1	Very unlikely	Since 1917, the site has been the property of HMS, with no public access, and has been fully protected as an ecological reserve since 1980."
Beaubien, E. G. and H. J. Freeland 2000: Spring phenology trends in Alberta, Canada: links to ocean temperature. *International Journal of Biometeorology* **44**(2): 53-59.	1	Unlikely	Change related to warming. "The long term trend (1900-1997) in timing of first blooming … shows an advance of 26 days."

Beaumont, L. J., I. A. W. McAllan and L. Hughes 2006: A matter of timing: changes in the first date of arrival and last date of departure of Australian migratory birds. *Global Change Biology* **12**(7): 1339-1354.	20	Very unlikely	"There was a significant relationship between average annual FAD (First Arrival Date) across all species and annual minimum temperature."
Both, C., A. V. Artemyev, B. Blaauw, R. J. Cowie, A. J. Dekhuijzen, T. Eeva, A. Enemar, L. Gustafsson, E. V. Ivankina, A. Jarvinen, N. B. Metcalfe, N. E. I. Nyholm, J. Potti, P. A. Ravussin, J. J. Sanz, B. Silverin, F. M. Slater, L. V. Sokolov, J. Torok, W. Winkel, J. Wright, H. Zang and M. E. Visser 2004: Large-scale geographical variation confirms that climate change causes birds to lay earlier. *Proceedings of the Royal Society of London Series B-Biological Sciences* **271**(1549): 1657.	9	Very unlikely	"Trends in spring temperature varied markedly between study sites, and across populations the advancement of laying date was stronger in areas were the spring temperature increased more, giving support to the theory that climate change causally affects breeding date advancement.”
Bradshaw, W. E. and C. M. Holzapfel 2001: Genetic shift in photoperiodic response correlated with global warming. *Proceedings of the National Academy of Sciences of the United States of America* **98**(25): 14509.	7	Very unlikely	The photoperiodic response is explained best by its correlation with rising temperatures.
Brooks, S. J. and H. J. B. Birks 2004: The dynamics of Chironomidae (Insecta : Diptera) assemblages in response to environmental change during the past 700 years on Svalbard. *Journal of Paleolimnology* **31**(4): 483-498.	1	Unlikely	At only one of the sites, changes may be related to the establishment of a human settlement close to the lake 70 years ago.

Brown, J. L., S. H. Li and N. Bhagabati 1999: Long-term trend toward earlier breeding in an American bird: A response to global warming? *Proceedings of the National Academy of Sciences of the United States of America* **96**(10): 5565-5569.	1	Very unlikely	"We cannot prove with correlation data that climate change caused the observed changes in lying dates…but other hypotheses are not convincing…Finally, our results with respect to the importance of minimum temperatures are in good agreement with a recent study of climate correlates of changes in community composition in Colorado."
Bunce, A., F. I. Norman, N. Brothers and R. Gales 2002: Long-term trends in the Australasian gannet (Morus serrator) population in Australia: the effect of climate change and commercial fisheries. *Marine Biology* **141**(2): 263-269.	2	Likely	"Discarded bycatch of both non-target quota and non-commercial species in the SEF (South East Fishery) has perhaps provided a valuable and substantial artificial increase in local food availability."
Butler, C. J. 2003: The disproportionate effect of global warming on the arrival dates of short-distance migratory birds in North America. *Ibis* **145**(3): 484.	100	Very unlikely	The "results are consistent with those expected under a scenario of global warming."
Chambers, L. E. 2005: Migration dates at Eyre Bird Observatory: links with climate change? *Climate Research* **29**: 157-165.	302	Very unlikely	"For most species, changes in migration dates were related to observed changes in the regional climate."
Chuine, I., P. Yiou, N. Viovy, B. Seguin, V. Daux and E. L. Ladurie 2004: Historical phenology: Grape ripening as a past climate indicator. *Nature* **432**(7015): 289-290.	1	Very unlikely	The authors used several methods to deduce past temperature records.

Cook, A. J., A. J. Fox, D. G. Vaughan and J. G. Ferrigno 2005: Retreating glacier fronts on the Antarctic Peninsula over the past half-century. *Science* **308**(5721): 541-544.	113	Very unlikely	Authors state that the "the pattern is broadly compatible with retreat driven by atmospheric warming, but the rapidity of the migration suggests that this may not be the sole driver of glacier retreat in this region." They go on to state that the other variable might be rising ocean temperatures (which is also related to global warming) and positive feedbacks associated with the loss of floating ice.
Corn, P. S. 2003: Amphibian breeding and climate change: Importance of snow in the mountains. *Conservation Biology* **17**(2): 622-625.	1	Unlikely	The main driving forces were snowmelt and air temperature.
D'Arrigo, R., G. Jacoby, D. Frank, N. Pederson, E. Cook, B. Buckley, B. Nachin, R. Mijiddorj and C. Dugarjav 2001: 1738 years of Mongolian temperature variability inferred from a tree-ring width chronology of Siberian pine. *Geophysical Research Letters* **28**(3): 543-546.	1	Very unlikely	The paper shows that, according to tree rings, the warmest conditions over the past millennium are during the 20th century.
Defila, C. and B. Clot 2001: Phytophenological trends in Switzerland. *International Journal of Biometeorology* **45**: 203.	1	Unlikely	Change related to temperature trends.
Daufresne, M., M. C. Roger, H. Capra and N. Lamouroux 2004: Long-term changes within the invertebrate and fish communities of the Upper Rhone River: effects of climatic factors. *Global Change Biology* **10**(1): 124-140.	1	Unlikely	"These patterns were significantly correlated with thermal variables, suggesting that shifts were the consequences of climatic warming."

Dyurgerov, M. B. and M. F. Meier 2005: Glaciers and the changing earth system: a 2004 snapshot. *Occasional Paper No. 58*, INSTAAR, University of Colorado at Boulder.	60	Unlikely	"Observational results also show an increasing glacier mass turnover and mass balance sensitivity to air temperature."
Field, D. B., T. R. Baumgarter, C. D. Charles, V. Ferreira-Bartrina and M. D. Ohman 2006: Planktonic foraminifera of the California current reflect 20th-centuary warming. *Science (Washington)* **311**: 63-66.	1	Exceptionally unlikely	"Increasing abundance of tropical/subtropical species throughout the 20th century reflect a warming trend superimposed on decadal-scale fluctuations. Decreasing abundances of temperate/sub polar species in the late 20th century indicate a deep, penetrative warming not observed in previous centuries."
Fitter, A. H. and R. S. R. Fitter 2002: Rapid changes in flowering time in British plants. *Science* **296**(5573): 1689.	71	Very unlikely	Correlations with the Central England temperature record were stronger than with NAO data in all cases.
Forbes, D. L., G. S. Parkes, G. K. Manson and L. A. Ketch 2004: Storms and shoreline retreat in the southern Gulf of St. Lawrence. *Marine Geology* (210): 169-204.	3	Very unlikely	Change is related to warming.
Forister, M. L. and A. M. Shapiro 2003: Climatic trends and advancing spring flight of butterflies in lowland California. *Global Change Biology* **9**(7): 1130-1135.	4	Very unlikely	"Climatic conditions are found to explain a large part of the variation in changing date of first flight."
Frauenfeld, O. W., T. Zhang, R. G. Barry, and D. Gilichinsky 2004: Interdecadal changes in seasonal freeze and thaw depths in Russia. *Journal of Geophysical Research*. **109**(D5101).	68	Very unlikely	"The change in the active layer was significantly related to air temperature. The change in freeze depth was also mostly influenced strongly by the freezing index and mean annual air temperature. Snow depth, though, was related to both."

Georges, C. 2004: 20th-century glacier fluctuations in the tropical Cordillera Blanca, Peru. *Arctic Antarctic and Alpine Research* **36**(1): 100-107.	1	Unlikely	The influence of precipitation fluctuations is small in this part of the Andes.
Gibbs, J. P. and A. R. Breisch 2001: Climate warming and calling phenology of frogs near Ithaca, New York, 1900-1999. *Conservation Biology* **15**(4): 1175.	3	Very unlikely	"The data suggest that climate has warmed in central New York State during this century and has resulted in earlier breeding in some amphibians…"
Hampton, S. E. 2005: Increased niche differentiation between two Conochilus species over 33 years of climate change and food web alteration. *Limnology and Oceanography* **50**(2): 421-426.	1	Very unlikely	The warming has actually allowed change to occur in spite of new competition. "the long-term warming trend has unexpectedly allowed *Conochilus* to persist in the lake by offering it a larger window of time in which to grow without its new competitor *Daphinia*.
Hennessy, K., P. Whetton, I. Smith, J. Bathols, M. Hutchinson and J. Sharples 2003. *The Impact of Climate Change on Snow Conditions in Mainland Australia*. Aspendale, Victoria, Australia, CSIRO.	3	Unlikely	Precipitation may also be a factor, although it has increased (not decreased) slightly.
Hodgkins, G. A., R. W. Dudley, et al. (2003). "Changes in the timing of high river flows in New England over the 20th Century." Journal Of Hydrology 278(1-4): 244-252.	27	Unlikely	"Winter/spring center of volume (WSCV) dates have become significantly earlier ($p < 0.1$) at all 11 river gauging stations in areas of New England where snowmelt runoff has the most effect on spring river flows. Most of this change has occurred in the last 30 years with dates advancing by 1-2 weeks. WSCV dates were correlated with March through April air temperatures ($r = -0.72$) and with January precipitation ($r = -0.37$)."

Inouye, D. W., B. Barr, K. B. Armitage and B. D. Inouye 2000: Climate change is affecting altitudinal migrants and hibernating species. *Proceedings of the National Academy of Sciences of the United States of America* **97**(4): 1630.	1	Very unlikely	"We also report a change in the phenology of a hibernating species that is correlated with changing air temperatures…"
Jacobs, S. S., C. F. Giulivi and P. A. Mele 2002: Freshening of the Ross Sea during the late 20th century. *Science* **297**(5580): 386-389.	1	Very unlikely	Authors rule out precipitation.
Jones, R. N., T. McMahon and J. M. Bowler 2001: Modelling historical lake levels and recent climate change at three closed lakes, Western Victoria, Australia (c.1840-1990). *Journal of Hydrology* **246**(1-4): 159-180.	1	Unlikely	Land use change did not contribute to declining water levels.
Jonzen, N., A. Linden, T. Ergon, E. Knudsen, J. O. Vik, D. Rubolini, D. Piacentini, C. Brinch, F. Spina, L. Karlsson, M. Stervander, A. Andersson, J. Waldenstrom, A. Lehikoinen, E. Edvardsen, R. Solvang and N. C. Stenseth 2006: Rapid advance of spring arrival dates in long-distance migratory birds. *Science* **312**(5782): 1959-1961.	5	Very unlikely	The rapid advance in arrival dates of long-distance migrants from Europe is due to climate-driven evolutionary changes in the timing of spring migration.

Juanes, F., S. Gephard and K. Beland 2004: Long-term changes in migration timing of adult Atlantic salmon (Salmo salar) at the southern edge of the species distribution. *Canadian Journal of Fisheries and Aquatic Sciences* **61**(12): 2392-2400.	4	Very unlikely	"We found that the change in migration timing were not unique to the Connecticut River stock and instead observed coherent patterns in the shift towards earlier peak migration dates across systems. The consistent shifts are correlated with long-term changes in temperature and flow and may represent a response to global climate change."
Karst-Riddoch, T. L., M. F. J. Pisaric and J. P. Smol 2005: Diatom responses to 20th century climate-related environmental changes in high-elevation mountain lakes of the northern Canadian Cordillera. *Journal of Paleolimnology* **33**(3): 265-282.	2	Exceptionally unlikely	"Our results confirm the sensitivity of diatoms from high-elevation mountain lakes to regional climate change in northwest Canada."
Kozlov, M. V. and N. G. Berlina 2002: Decline in length of the summer season on the Kola Peninsula, Russia. *Climatic Change* **54**(4): 387-398.	3	Likely	Phenological shifts during the observation period are much larger than could be expected from the slight (0.56degreesC) drop in temperatures during August-September, suggesting that the biotic effects of a very slight cooling have been enhanced by one or more unknown factors.
Kullman, L. 2003: Recent reversal of Neoglacial climate cooling trend in the Swedish Scandes as evidenced by mountain birch tree-limit rise. *Global and Planetary Change* **36**(1-2): 77.	1	Exceptionally unlikely	Authors state that "there are no obvious signs of human induced disturbance, e.g. logging, agro-pastoralism or burning within the upper reaches of the birch forest or higher…"
Ledneva, A., A. J. Miller-Rushing, R. B. Primack and C. Imbres 2004: Climate change as reflected in a naturalist's diary, Middleborough, Massachusetts. *Wilson Bulletin* **116**(3): 224-231.	5	Exceptionally unlikely	Twenty-two species responded to warming temperatures with 4 species showing statistically significant earlier activity in year with warmer temperatures…

Lips, K. R., J. R. Mendelson, A. Munoz-Alonso, L. Canseco-Marquez and D. G. Mulcahy 2004: Amphibian population declines in montane southern Mexico: resurveys of historical localities. *Biological Conservation* **119**(4): 555-564.	4	Very likely	Pollution, warming, habitat disturbance, and the chytrid fungi are all involved.
Magnuson, J. J., D. M. Robertson, B. J. Benson, R. H. Wynne, D. M. Livingstone, T. Arai, R. A. Assel, R. G. Barry, V. Card, E. Kuusisto, N. G. Granin, T. D. Prowse, K. M. Stewart and V. S. Vuglinski 2000: Historical trends in lake and river ice cover in the Northern Hemisphere. *Science* **289**(5485): 1743-1746.	17	Very unlikely	A few records before 1846 suggest that long-term changes toward later freezing and earlier breakup dates were already occurring, but at slower rates.
Matsumoto, K., T. Ohta, M. Irasawa and T. Nakamura 2003: Climate change and extension of the Ginkgo biloba L. growing season in Japan. *Global Change Biology* **9**(11): 1634.	3	Very unlikely	We found high correlations not only between budding dates and air temperature in spring but also between leaf-fall dates and air temperature in autumn.

Menzel, A., T. H. Sparks, N. Estrella, E. Koch, A. Aasa, R. Ahas, K. Alm-Kübler, P. Bissolli, O. Braslavská, A. Briede, F. M. Chmielewski, Z. Crepinsek, Y. Curnel, Å. Dahl, C. Defila, A. Donnelly, Y. Yolanda Filella, K. Katarzyna Jatczak, F. Finn Måge, A. Antonio Mestre, Ø. Nordli, J. Peñuelas, P. Pirinen, V. Remišová, H. Scheifinger, M. Striz, A. Susnik, A. Vliet J.H. van, F.-E. Wielgolaski, S. Zach and A. Zust 2006: European phenological response to climate change matches the warming pattern. *Global Change Biology* **12**: 1969-1976.	>28,000	Unlikely	Phenology related to warming. Without warming the dates should be stable. Other driving forces do not seem to be related. There is some discussion of CO2 directly influencing phenology, however there are no clear results of direction (advancing or delaying). Concerning trees, older trees seem to leaf out later than younger ones, if you have longer time series on one specific object, the onset dates should be later with time due to aging, not earlier as observed due to warming.

Michelutti, N., M. S. V. Douglas, et al. (2003). "Diatom response to recent climatic change in a high arctic lake (Char Lake, Cornwallis Island, Nunavut)." *Global and Planetary Change* 38(3-4): 257-271.	1	Very unlikely	"In general, there were no major differences between our water quality data and those collected 30 years earlier, showing that Char Lake is still oligotrophic, slightly alkaline, and dilute. However, a diatom-based paleolimnological analysis revealed that a subtle, yet distinct species assemblage shift has occurred beginning around 1987. The timing of this species shift does not correspond to the deposition of atmospherically transported persistent organic pollutants into the lake (beginning in the early 1950s) or to minor disturbances within its catchment (early 1970s). Instead, these subtle diatom changes are consistent with recent climatic changes during 1988-1997 (as documented by local meteorological measurements), and are likely related to reduced summer ice cover and a longer growing season."
Mills, A. M. 2005: Changes in the timing of spring and autumn migration in North American migrant passerines during a period of global warming. *Ibis* **147**(2): 259-269.	7	Unlikely	"Autumn responses were more prevalent, however, and in some cases more dramatic with six of 13 species showing delayed migration."
Mote, P. W., A. F. Hamlet, M. P. Clark and D. P. Lettenmaier 2005: Declining mountain snowpack in western North America. *Bulletin of the American Meteorological Society* **86**(1): 39.	160	Unlikely	Precipitation might also be a variable, but is not the main driver.

Murphy-Klassen, H. M., T. J. Underwood, S. G. Sealy and A. A. Czyrnyj 2005: Long-term trends in spring arrival dates of migrant birds at Delta Marsh, Manitoba, in relation to climate change. *Auk* **122**(4): 1130-1148.	27	Very unlikely	"Fifteen species showed significantly earlier arrivals over time and a significant relationship between arrival date and temperature."
O'Reilly, C. M., S. R. Alin, P. D. Plisnier, A. S. Cohen and B. A. McKee 2003: Climate change decreases aquatic ecosystem productivity of Lake Tanganyika, Africa. *Nature* **424**(6950): 766-768.	2	Exceptionally unlikely	"Other possible explanations for a shift toward more negative carbon isotopes in Lake Tanganyika, such as the decrease in atmospheric isotope ratio 13C from fossil fuel combustion (The Suess effect), and increase in terrestrial organic matter, or a change in phytoplankton composition, can be discounted, and the shift occurs independently of the rates of sediment mass accumulation... The timing of this shift toward more negative carbon isotope ratios coincides with changes in climatic temperature records..."
Oerlemans, J. 2005: Extracting a climate signal from 169 glacier records. *Science* **308**(5722): 675-677.	124	Unlikely	"The possibility that changes in precipitation are responsible for part of the observed glacier fluctuations cannot be excluded. However, a very large drying on a global scale would be needed to explain the worldwide glacier retreat, and there is no independent evidence at all of such a phenomenon."
Orviku, K., J. Jaagus, A. Kont, U. Ratas and R. Rivis 2003: Increasing activity of coastal processes associated with climate change in Estonia. *Journal of Coastal Research* **19**(2): 364-375.	1	Very unlikely	Area is remote and not developed.

Penuelas, J., J. Filella, and P. Comas, 2000: Changed plant and animal life cycles from 1952 to 2000 in the Mediterranean region. *Global Change Biology*, 8, 531-544.	99	Unlikely	Temperature was significantly correlated with the changes.
Perren, B. B., R. S. Bradley and P. Francus 2003: Rapid lacustrine response to recent High Arctic warming: A diatom record from Sawtooth Lake, Ellesmere Island, Nunavut. *Arctic Antarctic and Alpine Research* **35**(3): 271-278.	1	Exceptionally unlikely	"These records suggest that diatoms in high arctic lakes and ponds, regardless of lake size, latitude, or altitude, have most likely responded to a decline in ice cover and a concomitant increase in light availability, growing season length, epiphytic habitats, and increase nutrient supply, all of which have likely occurred as a result or recent warming."
Primack, D., C. Imbres, R. Primack, A. Miller-Rushing and P. Del Tredici 2004: Herberium specimens demonstrate earlier flowering times in response to warming in Boston. *American Journal of Botany* **91**(8): 1260-1264.	1	Very unlikely	"We were able demonstrate a significant response of plant flowering time to changing spring temperatures over the past century. Specifically, plants are now flowering earlier because of warmer spring temperatures, as shown by multiple regression."
Pulsalmaa, B., B. Nyamsuren and B. Buyndalai 2004: Trends in River and Lake Ice in Mongolia. AIACC www.aiaccproject.org	8	Very unlikely	Such changes in freshwater ice phenology and thickness are best explained by temperature changes, and air temperatures has increased 1.66 degrees C in winter and 3.61 degrees C in spring-autumn.
Regehr, E. V., S. C. Amstrup and I. Stirling 2006: *Polar bear population status in the southern Beaufort Sea*, U.S. Geological Survey Open-File Report 2000-1337**:** 20.	1	Very unlikely	Authors state that the events are related to ice-free seasons that have occurred in the region in recent years.

Richardson, A. J. and D. S. Schoeman 2004: Climate impact on plankton ecosystems in the Northeast Atlantic. *Science* **305**(5690): 1609-1612.	0	Very unlikely	"We show that sea surface warming in the Northeast Atlantic is accompanied by increasing phytoplankton abundance in cooler regions and decreasing phytoplankton abundance in warmer regions."
Rignot, E., Rivera, A. and Casassa G., 2003: Contribution of the Patagonia Icefields of South America to Sea Level Rise. *Science*. **302**: 434-437.	45	Unlikely	The change is being accelerated because of ice-melt dynamics, which means ice creep (ice thinning from longitudinal stretching) and accelerated calving (ice loss to the ocean or lakes).
Ron, S. R., W. E. Duellman, L. A. Coloma and M. R. Bustamante 2003: Population decline of the Jambato Toad *Atelopus ignescens* (Anura: Bufonidae) in the Andes of Ecuador *Journal of Herpetology* **37**(1): 116-126.	1	Unlikely	"Climate data show that 1987, the year previous to the last record of *A. Ignescens*, was particularly warm and dry." Temperature is related to population decline; other driving forces may have contributed to disappearance.
Rotzer, T., M. Wittenzeller, H. Haeckel and J. Nekovar 2000: Phenology in central Europe - differences and trends of spring phenophases in urban and rural areas. *International Journal of Biometeorology* **44**(2): 60.	26	Very unlikely	Other driving forces were considered and discounted.
Ruhland, K., A. Presnitz and J. P. Smol 2003: Paleolimnological evidence from diatoms for recent environmental changes in 50 lakes across Canadian arctic treeline. *Arctic, Antarctic and Alpine Research,* **35**: 110-123.	1	Exceptionally unlikely	"Our data make a strong case for dismissing acidification, nutrient enrichment and contamination as possible causes for the diatom changes observed in this study."

Smol, J. P., A. P. Wolfe, H. J. B. Birks, M. S. V. Douglas, V. J. Jones, A. Korhola, R. Pienitz, K. Ruhland, S. Sorvari, D. Antoniades, S. J. Brooks, M. A. Fallu, M. Hughes, B. E. Keatley, T. E. Laing, N. Michelutti, L. Nazarova, M. Nyman, A. M. Paterson, B. Perren, R. Quinlan, M. Rautio, E. Saulnier-Talbot, S. Siitoneni, N. Solovieva and J. Weckstrom 2005: Climate-driven regime shifts in the biological communities of arctic lakes. *Proceedings of the National Academy of Sciences of the United States of America* **102**(12): 4397-4402.	32	Exceptionally unlikely	The remoteness of these sites, coupled with the ecological characteristics of taxa involved, indicate that changes are primarily driven by climate warming through the lengthening of the summer growing season and related to limnological changes.
Sorvari, S., A. Korhola and R. Thompson 2002: Lake diatom response to recent Arctic warming in Finnish Lapland. *Global Change Biology* **8**(2): 171-181.	1	Exceptionally unlikely	Authors ruled out acidic or anthropogenic deposition.
Stervander, M., K. Lindstrom, N. Jonzen and A. Andersson 2005: Timing of spring migration in birds: long-term trends, North Atlantic Oscillation and the significance of different migration routes. *Journal of Avian Biology* **36**(3): 210-221.	10	Unlikely	NAO was a factor. But a long-term trend was observed.
Stewart, I. T., D. R. Cayan and M. D. Dettinger 2005: Changes toward earlier streamflow timing across western North America. *Journal of Climate* **18**(8): 1136-1155.	133	Very unlikely	Although these temperature changes are partly controlled by the decadal-scale Pacific climate mode [Pacific decadal oscillation (PDO)], a separate and significant part of the variance is associated with a springtime warming trend that spans the PDO phases.

Sumner, P. D., K. I. Meiklejohn, J. C. Boelhouwers and D. W. Hedding 2004: Climate change melts Marion Island's snow and ice. *South African Journal of Science* **100**(7-8): 395-398.	1	Very unlikely	"Climatic amelioration and declining precipitation over the past four decades are responsible for the disappearance of a snowline and the 'Ice Plateau'."
Van Duivenbooden, N., S. Abdoussalam and A. B. Mohamed 2002: Impact of climate change on agricultural production in the Sahel - Part 2. Case study for groundnut and cowpea in Niger. *Climatic Change* **54**: 349-368.	3	Unlikely	"The change that took place in the climatic conditions is certainly not the only cause of the drop in groundnut production. However, it served as a catalyst for a number of other causes that accelerated such a decline…"
Van Vliet, A. J. H., A. Overeem, R. S. De Groot, A. F. G. Jacobs and F. T. M. Spieksma 2002: The influence of temperature and climate change on the timing of pollen release in the Netherlands. *International Journal of Climatology* **22**(14): 1757-1767.	1	Very unlikely	"The results indicate that there is a strong correlation between temperature and start of pollen season."
Vincent, C., G. Kappenberger, F. Valla, A. Bauder, M. Funk and E. Le Meur 2004: Ice ablation as evidence of climate change in the Alps over the 20th century. *Journal of Geophysical Research-Atmospheres* **109**(D10).	1	Very unlikely	Detailed observations on the Sarennes glacier show that the origin of this strong increase in summer ablation since 1982 is not only a rise in the summer melting rate, but also an increase in the ablation period during the months of September and October.
Walter, K. M., S. A. Zimov, J. P. Chanton, D. Verbyla and F. S. Chapin 2006: Methane bubbling from Siberian thaw lakes as a positive feedback to climate warming. *Nature* **443**(7107): 71-75.	1	Very unlikely	"We…estimate that an expansion of thaw lakes between 1974 and 2000, which was concurrent with regional warming."

Williams, T. A. and M. T. Abberton 2004: Earlier flowering between 1962 and 2002 in agricultural varieties of white clover. *Oecologia* **138**(1): 122-126.	1	Very unlikely	"First flowering dates were significantly negatively correlated with minimum and maximum temperatures during February and March and soil temperatures between January and April."
Wolfe, D. W., M. D. Schwartz, A. N. Lakso, Y. Otsuki, R. M. Pool and N. J. Shaulis 2005: Climate change and shifts in spring phenology of three horticultural woody perennials in northeastern USA. *International Journal of Biometeorology* **49**(5): 303-309.	5	Very unlikely	"The vines monitored were the same vines in the long-term trial that has been continually managed in the same way since 1959."
Yom-Tov, Y. 2001: Global warming and body mass decline in Israeli passerine birds. *Proceedings of the Royal Society of London Series B-Biological Sciences* **268**(1470): 947.	4	Unlikely	"It is suggested that the above declines in body mass and tarsus length are due to global warming…"
Yoo, J. C. and P. D'Odorico 2002: Trends and fluctuations in the dates of ice break-up of lakes and rivers in Northern Europe: the effect of the North Atlantic Oscillation. *Journal of Hydrology* **268**(1-4): 100-112.	3	Very unlikely	Though NAO has a weak effect, "it is argued that other climatic forcings, related to CO2-induced regional and global warming, acting at the end of the ice season, are able to induce pronounced trends in the regime of spring temperature and have an important impact on the cryosphere leading to the earlier occurrence of ice break-up observed in the last several decades"
Yoshikawa, K. and L. D. Hinzman 2003: Shrinking thermokarst ponds and groundwater dynamics in discontinuous permafrost near Council, Alaska. *Permafrost and Periglacial Processes* **14**(2): 151-160.	1	Very unlikely	Area is remote.

Note: Likelihood refers to a probabilistic assessment of a statement being true, based on expert judgment. Categories here and in the paper are based on IPCC AR4.

Terminology	Likelihood of being correct
Virtually certain	>99% probability of occurrence
Very likely	90 to 99% probability
Likely	66 to 90% probability
About as likely as not	33 to 66% probability
Unlikely	10 to 30% probability
Very unlikely	1 to 10% probability
Exceptionally unlikely	-<1% probability

Table SI-2. Effects of land-use change on climate.

Region	Main modeled response	Time	Publication
Temperate latitudes	cooling of up to 0.7C in summer and 1.1C in winter	1987-2002	Bounoua, L., DeFries, R., Collatz, G. J., Sellers, P. & Khan, H. Effects of land cover conversion on surface climate. Climatic Change 52, 29-64 (2002).
Mid-latitudes and Asia	strong cooling (~2K)	Pre-industrial - 1990s	Feddema, J. et al. A comparison of a GCM response to historical anthropogenic land cover change and model sensitivity to uncertainty in present-day land cover representations. Climate Dynamics 25, 581-609 (2005).
Central North America, Eurasian agricultural belt, and China	1-2K lower in winter and spring	1750-1990s	Betts, R. A., Falloon, P. D., Goldewijk, K. K. & Ramankutty, N. Biogeographical effects of land use on climate: Model simulations of radiative forcing and large-scale temperature change. Agricultural and Forest Meteorology 142, 216-233 (2007).

Parts of India and Sahel	slight (< 1K) warming	1750-1990s	Betts, R. A., Falloon, P. D., Goldewijk, K. K. & Ramankutty, N. Biogeographical effects of land use on climate: Model simulations of radiative forcing and large-scale temperature change. Agricultural and Forest Meteorology 142, 216-233 (2007).
Global	decrease in mean annual temperature in the range of 0.13-0.25C	1000-1992	Brovkin, V. et al. Biogeophysical effects of historical land cover changes simulated by six Earth system models of intermediate complexity. Climate Dynamics 26, 587-600 (2006).
	cooling of 0.06-0.22C	1700-1992	Matthews, H. D., Weaver, A. J., Meissner, K. J., Gillett, N. P. & Eby, M. Natural and anthropogenic climate change: incorporating historical land cover change, vegetation dynamics and the global carbon cycle. Climate Dynamics 22, 461-479 (2004).

Statistical and spatial pattern analysis

The percentages of observed changes in natural systems that were consistent and not consistent with warming were determined on global and continental scales. Continent boundaries were based on previous regional climate studies [4, 5]. The majority (about 90% of the >29,500 data series of changes in these systems at the global scale have been in the direction expected as a response to warming. For a two-tailed Z test at .01 confidence level, test results indicate that the percentage of changes consistent with warming is statistically different from .5 (with $p<<0.001$), which means that we can reject the null hypothesis of equal change in both the expected and opposite directions.

The spatial distributions of the observed changes and the observed regional temperatures trends over 1970-2004 were then compared using spatial pattern analysis and a 5°×5° latitude-longitude grid over the globe. Two different gridded observed temperature datasets were used: HadCRUT3[2] and GHCN-ERSST[3].

The spatial patterns of the observed systems changes were compared with the observed temperature trends using two different pattern comparison measures. These were

(i) a binary pattern congruence (uncentred pattern correlation) between the gridded binary field of system responses consistent (not consistent) with warming and the gridded field of positive (negative) temperature trends, and

(ii) a pattern congruence between the gridded binary field of system responses and the gridded field of standardized temperature trends (the actual 35-year temperature trends divided by the standard deviation of 35-year temperature trends due to natural internal climate variations).

To assess the significance of these observed measures of pattern agreement, global temperature trend data were obtained from long control simulations with seven different coupled ocean-atmosphere climate models to represent the range of 35-year temperature trends across the globe due to natural climate variations (Table SI-3). These control simulations include no changes in external forcing of the climate system and represent the natural internal variability of the climate system on multi-decadal time scales. The global temperature trend fields from the climate models represent the spatial coherence and decadal variability of natural internal temperature variations. The control model surface temperature data were obtained from the WCRP CMIP3 multi-model archive at PCMDI and 3400 years were used from seven climate models: CGCM1 (500 years), GFDL_CM2.0 (500 years), GFDL_CM2.1 (500 years), MIROC3.2 (medres) (500 years), MPI-ECHAM5 (500 years), MRI-CGCM2.3.2 (350 years), and NCAR PCM (550 years). The 35-year linear trends at each grid cell were calculated from 50% overlapping 35-year periods from each of the control runs, providing 192 different 35-year trend estimates from the total of 3400 years of control model data. For each of the measures, the observed values for the two different observed temperature trend datasets were compared with the distributions obtained using temperature trends due to internal climate variability, as represented by the climate models.

Table SI-3 Climate models used in the spatial analysis of temperature trends

Models	Grid cells around a latitude circle (Δlongitude)	Grid cells along a meridian (Δlatitude)	Start year	End year	Length (year)	Netcdf file names from CMIP3 multi-model archive at PCMDI
CGCM3.1	96 (3.75°)	48 (3.75°)	1850	2349	500	tas_a1_picntrl_cgcm3.1_t47_1850_2349.nc
GFDL_CM2.0	144 (2.5°)	90 (2.0°)	1860	2359	500	tas_A1.000101-050012.nc
GFDL_CM2.1	144 (2.5°)	90 (2.0°)	1860	2359	500	tas_A1.000101010012.nc, tas_A1.010101-020012.nc, tas_A1.020101-030012.nc, tas_A1.030101-040012.nc, tas_A1.040101-050012.nc
MIROC3.2 (medres)	128 (2.8°)	64 (2.8°)	1850	2349	500	tas_A1.nc
MPI-ECHAM5	192 (1.88°)	96 (1.88°)	1860	2359	500	tas_A1.nc
MRI-CGCM2.3.2	128 (2.8°)	64 (2.8°)	1851	2200	350	tas_A1.1851-1900.nc, tas_A1.1901-2000.nc, tas_A1.2001-2100.nc, tas_A1.2101-2200.nc
NCAR_PCM	128 (2.8°)	64 (2.8°)	1870	2419	550	tas_A1.nc

Note: All model temperature data were averaged onto a common 5° × 5° latitude-longitude grid for comparison with the observed temperature trend.

Pattern congruence analysis

We consider a five degree latitude-longitude grid across the globe. Let the combined observed responses of all natural systems in each grid cell be R_i , a binary variable with value of +1 when 80% or more of the observations in an individual gridcell were consistent with warming (as reported in the original studies) and -1 when the response is <80% consistent with warming. Let the observed linear temperature trend at each grid cell over the period 1970 to 2004 be T_i (in units of degrees per decade). The temperature trends are represented either as a binary variable $B_i = \mathrm{sgn}(T_i)$ or as the standardised temperature trends $Z_i = T_i / \sigma_i$ where σ_i is the standard deviation of 35-year temperature trends at each grid cell due to natural internal climate variations. Two measures of the agreement between the spatial patterns of the observed temperature trends and the observed responses of the natural systems are the pattern congruence (uncentred pattern correlation) between the binary temperature trends B_i and the responses R_i and the pattern congruence between the standardised temperature trends Z_i and the responses R_i. The pattern congruence is

$$C_B = \frac{N\sum_{i=1}^{N} B_i R_i}{\sum_{i=1}^{N} B_i^2 \sum_{i=1}^{N} R_i^2} \text{ or } C_Z = \frac{N\sum_{i=1}^{N} Z_i R_i}{\sum_{i=1}^{N} Z_i^2 \sum_{i=1}^{N} R_i^2}$$

for the two different temperature trend field variables.

The pattern congruence was calculated between the control model temperature trend field from each of the 35-year periods and the observed natural system response field, providing a distribution of 192 values of each test parameter for natural temperature variations (Table SI-4). The control model temperature fields retain the spatial coherence of variations of the surface temperature trends, so the distribution of the test parameters accounts for spatial coherence of surface temperature in the climate system. The distributions of the test parameter were ranked and the 10%, 5% and 1% significance levels were estimated from the ranked distributions. Comparison of the actual pattern congruence values for the observed temperature trend field with the distributions from the control model runs provides estimates of the significance levels of the observed congruence values. In cases where the observed value far exceeds the full distribution of values from the model control runs, the significance value is reported as <<1%. We only conclude significant attribution results when both spatial statistics methods and both datasets show significant results.

Table SI-4 Spatial pattern congruence results

	C_B HadCRUT3	C_Z HadCRUT3	C_B GHCN-ERSST	C_Z GHCN-ERSST
Global	0.64 (<<1%) (183 cells)	0.62 (<<1%) (183 cells)	0.71 (<<1%) (203 cells)	0.68 (<<1%) (203 cells)
Africa	1.0 (not sig) (3 cells)	0.94 (~10%) (3 cells)	1.0 (not sig) (5 cells)	0.96 (~5%) (5 cells)
Asia	0.76 (<<1%) (42 cells)	0.70 (<5%) (42 cells)	0.72 (<1%) (58 cells)	0.72 (<<1%) (58 cells)
Australia NZ	1.0 (~5%) (4 cells)	0.93 (<5%) (4 cells)	0.50 (not sig) (4 cells)	0.82 (~10%) (4 cells)
Europe	0.60 (<10%) (33 cells)	0.58 (~10%) (33 cells)	0.70 (<5%) (33 cells)	0.64 (<5%) (33 cells)
North America	0.56 (<5%) (52 cells)	0.52 (~5%) (52 cells)	0.67 (<1%) (55 cells)	0.59 (<5%) (55 cells)
Latin America	1.0 (not sig) (5 cells)	0.86 (not sig) (5 cells)	1.0 (not sig) (5 cells)	0.94 (~5%) (5 cells)

These pattern correlation tests lead to the following conclusions on the agreement between the spatial patterns of responses of natural systems and the spatial patterns of temperature changes. For the globe, the agreement is highly significant and is very unlikely to be explained by natural climate variability or other factors affecting the natural systems. At the continental scale, the strongest agreements between the temperature responses and the observed system responses are in Asia and North America, which have the largest spatial coverage of response data. For Europe, the agreement is less strong (generally significant at better than the 10% level) because of the smaller area with observed system responses and the large coherent natural climate variability in this region. For the other continents, with much smaller coverage of significant observed system responses, the pattern congruences show some marginally significant pattern agreements but the results differ between the different temperature trend datasets and the data coverage is considered to be too sparse for these results to be robust.

Categorical Analysis

In addition to the pattern congruence analysis, a separate categorical analysis was used to assess the agreement between the spatial patterns of significant changes in systems and significant warming (Table SI-5). This analysis determined the fraction of 5^{o}x5^o cells with significant observed changes in systems and temperature trends (over 1970-2004 from HadCRUT3[2] in different categories (significant warming, warming, cooling, significant cooling).

The expected fractions of cells within each category were determined using the null hypothesis:
(i) significant observed changes in systems are equally likely in each direction,
(ii) temperature trends are due to natural climate variations and are normally distributed, and
(iii) there is no relationship between significant changes in systems and co-located temperature trends.

It should be noted that the null hypothesis can be rejected if any one of these assumptions is not valid and so it cannot be used to directly assess the confidence in the relationship between the significant changes in systems and co-located temperature trends. The results from the categorical analysis are presented below to show the agreement between the spatial patterns of significant changes in systems and significant warming globally and in each continent. These results are shown in graphical form in Figure 3. The analysis was repeated using a second global gridded temperature dataset (GHCN-ERSST) and there were no significant differences in the results.

Table SI-5: Comparison of significant observed changes in physical and biological systems with regional temperature changes.

Fraction of 5^{o}x5^o cells with significant observed changes in systems and temperature changes (over 1970-2004 from HadCRUT3[2] in different categories (significant warming, warming, cooling, significant cooling). Expected values shown in parentheses are for the null hypotheses defined above.

The right hand column repeats the analysis without assuming (i) above and only considers significant observed changes in systems that are consistent with warming, in order to avoid the possible effects of publication or research biases.

Globe

	Significant observed changes in systems equally likely in each direction		**Significant observed changes in systems consistent with warming**
Temperature cells	**Cells with significant observed change consistent with warming**	**Cells with significant observed change not consistent with warming**	**Cells with significant observed change consistent with warming**
Significant warming	51% (2.5%)	7% (2.5%)	58% (5%)
Warming	31% (22.5%)	6% (22.5%)	35% (45%)
Cooling	4% (22.5%)	0% (22.5%)	5% (45%)
Significant cooling	2% (2.5%)	0% (2.5%)	2% (5%)

Africa (3 cells with significant observed changes)

Temperature cells	**Cells with significant observed change consistent with warming**	**Cells with significant observed change not consistent with warming**	**Cells with significant observed change consistent with warming**
Significant warming	67% (2.5%)	0% (2.5%)	67% (5%)
Warming	33% (22.5%)	0% (22.5%)	33% (45%)
Cooling	0% (22.5%)	0% (22.5%)	0% (45%)
Significant cooling	0% (2.5%)	0% (2.5%)	0% (5%)

Asia (42 cells with significant observed changes)

Temperature cells	Cells with significant observed change consistent with warming	Cells with significant observed change not consistent with warming	Cells with significant observed change consistent with warming
Significant warming	67% (2.5%)	10% (2.5%)	76% (5%)
Warming	21% (22.5%)	2% (22.5%)	24% (45%)
Cooling	0% (22.5%)	0% (22.5%)	0% (45%)
Significant cooling	0% (2.5%)	0% (2.5%)	0% (5%)

Australia-New Zealand (4 cells with significant observed changes)

Temperature cells	Cells with significant observed change consistent with warming	Cells with significant observed change not consistent with warming	Cells with significant observed change consistent with warming
Significant warming	0% (2.5%)	0% (2.5%)	0% (5%)
Warming	100% (22.5%)	0% (22.5%)	100% (45%)
Cooling	0% (22.5%)	0% (22.5%)	0% (45%)
Significant cooling	0% (2.5%)	0% (2.5%)	0% (5%)

Europe (33 cells with significant observed changes)

Temperature cells	Cells with significant observed change consistent with warming	Cells with significant observed change not consistent with warming	Cells with significant observed change consistent with warming
Significant warming	45% (2.5%)	6% (2.5%)	54% (5%)
Warming	33% (22.5%)	9% (22.5%)	39% (45%)
Cooling	6% (22.5%)	0% (22.5%)	7% (45%)
Significant cooling	0% (2.5%)	0% (2.5%)	0% (5%)

North America (52 cells with significant observed changes)

Temperature cells	Cells with significant observed change consistent with warming	Cells with significant observed change not consistent with warming	Cells with significant observed change consistent with warming
Significant warming	52% (2.5%)	10% (2.5%)	63% (5%)
Warming	25% (22.5%)	8% (22.5%)	30% (45%)
Cooling	2% (22.5%)	0% (22.5%)	2% (45%)
Significant cooling	4% (2.5%)	0% (2.5%)	5% (5%)

Latin America (5 cells with significant observed changes)

Temperature cells	Cells with significant observed change consistent with warming	Cells with significant observed change not consistent with warming	Cells with significant observed change consistent with warming
Significant warming	100% (2.5%)	0% (2.5%)	100% (5%)
Warming	0% (22.5%)	0% (22.5%)	0% (45%)
Cooling	0% (22.5%)	0% (22.5%)	0% (45%)
Significant cooling	0% (2.5%)	0% (2.5%)	0% (5%)

Supplementary Material References

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